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An education curriculum for space science in developing countries

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Abstract

A space science education curriculum incorporating recent discoveries and designed around the author's two recent books and a supporting website is proposed. This curriculum complements, extends and updates the worldwide approach to developing space science under the auspices of the UN Office for Outer Space Affairs, including its Space and Atmospheric Science Education Curriculum. A variety of pedagogical tools are suggested for educating and stimulating a broad cross-section of students, including topics of direct human concern and the use of the worldwide web. The proposed curriculum is in two parts: the Sun, and the Moons and Planets. The content of each part is described through major scientific themes, supplemented by descriptions of their key ideas and fundamental discoveries. Our proposed curriculum could be supplemented by a discussion of artificial satellites, used for peaceful scrutiny of our globe. Other satellites are used for military purposes, which should always remain separate from space science.
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1. Introduction

A comprehensive education curriculum in Space Science, at the university level, will enable developing countries to build a general capability in the field, and to educate and stimulate students in other disciplines. Such a curriculum should be accessible, well paced and set at the right level, while also including topics of direct human concern and visually exciting images that will capture the interest of the students.

To this end, I have designed a curriculum that complements, extends and updates the Space and Atmospheric Science Education Curriculum developed for the United Nations Office for Outer Space Affairs (OOSA) [1]. That curriculum was designed for the UN-affiliated regional centers for space science and technology [2], and it focuses mainly on the Earth's atmosphere, ionosphere and magnetic fields, as well as the solar wind and its interaction with our planet. Since these topics include discoveries by the very first artificial satellites and spacecraft in the late 1950s and the 1960s, showing that space is not empty and giving rise to the new discipline of space science, they remain essential ingredients for any modern education curriculum.

Nevertheless, the field has grown during the past two decades to include detailed studies of the Sun, from its interior to its varied particle and radiative output, as well as the fascinating and diverse surfaces of all the major planets and large moons, demonstrating the widespread presence of impact craters, volcanoes and water in the Solar System.

A uniform approach to these modern developments is presented in the following curriculum, whose two parts are the subject of my recent books [3,4]. An abridged version of these books is given at the NASA's Cosmos website [5].

A comprehensive scholarly account of solar astrophysics, which includes recent solar spacecraft missions and hundreds of seminal references is given in [6], and the mathematical formulae that deal with all aspects of astrophysics are given in [7]. Most of the original sources referenced in these encyclopedic volumes are available on the web through the NASA Astrophysics Data System [8].

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2. Pedagogical tools

During the past decade, OOSA has encouraged and supported a worldwide approach to developing space science [9], including the international UN/ESA workshops in basic space science [10] and the establishment of small astronomical facilities using telescopes donated by Japan [11]. A truly international approach is adopted in a proposed World Space Observatory, currently designed for ultraviolet observations with a broad cross section of participating groups and countries [12].

Another tool for developing Space Science is, of course, education of the next generation of space scientists, as well as curious persons in all walks of life. The two books that serve as a basis for the Space Science Education Curriculum given below provide an example. They are written in a concise, light and uniform style, describing scientific concepts in straightforward terms with numerous metaphors, similes and analogies that make them accessible to the general reader. The text is humanized by interspersing it with personal recollections of key players in space science. Topics of direct human concern are also provided, such as the threats of solar activity and space weather to astronauts, satellites and other spacecraft; the possibility of widespread destruction of civilization resulting from an asteroid collision with Earth; ozone depletion and global warming; and the possibility of life outside the Earth.

The internet and worldwide web provide a dramatic new method of accessing and sharing information in space science. The web is an open, non-proprietary and free method of communicating knowledge that is available to anyone with a personal computer, cutting across the borders of countries and through elitist institutions and power structures. It helps make Space Science a more democratic endeavor, while also allowing the public to enjoy vicarious exploration of outer space.

An example of web-related education is NASA's Cosmos website [5], which shares the excitement and scientific content of space science with university students, while also enhancing public accessibility and exposure to modern results in the field. This website can be used as an educational tool for teachers and students following the education curriculum given in this article. It can be used in public or private school education at all advanced levels from secondary education through universities and colleges, while tapping into the interest of the younger generation, which has become increasingly dependent on visual information through the widespread use of television and the internet. During the past year, our website has had more than a million hits, demonstrating the growing interest in this form of electronic education.

The pedagogical approach used in the NASA's Cosmos website employs different methods to present similar information in various forms. They include an Overview, which provides key ideas and fundamental discoveries in a capsule form; a Tutorial, which provides text and figures, abridged from the author's lengthier books; and Images, which provides more than 450 close-up, high-resolution images from spacecraft and more than 100 line drawings. Additional websites for individual spacecraft and space science institutions are given in the Resources part of the website.

3. Education curriculum for the Sun

Our life-sustaining Sun is the topic of one half of our Space Science Education Curriculum. This material follows the organization of *The Cambridge Encyclopedia of the Sun* [3], and the Sun Navigation Tab of the NASA's Cosmos website.

After the introductory material that deals with the Sun as a star and places it within our Galaxy and Universe, the curriculum progresses from the center of the Sun through its outer atmosphere and winds to the Earth, and then to the telescopes and other instruments that are used to observe the Sun from the ground and space. The initial three scientific themes are:

1. The Sun's domain.
2. The Sun as a star.
3. What makes the Sun shine?

The first theme deals with fundamental physical properties of the Sun and its retinue of planets, together with basic scientific principles concerning radiation, gravity, atomic structure and spectroscopy, as well as the age and origin of the Solar System.

The second theme places the Sun within the context of the other stars, the galaxies and the expanding Universe. It also includes basic scientific principles, including the distance, mass, luminosity and evolution of stars, and the origin and fate of the Universe.

The third theme describes how the Sun shines by thermonuclear reactions within its hot, dense core, and provides an up-to-date treatment of the solar neutrino problem.

Stellar and galaxy evolution, as well as basic cosmology, are elements of the Space and Atmospheric Science Education Curriculum [1], but a brief introduction to these topics is sufficient for a course in space science. The material could be developed into a complete course that focuses on the Cosmos outside the Solar System, as discovered by radio, visible light and X-ray telescopes on the ground and in space.

The next four themes highlight the discoveries of three modern solar spacecraft, Yohkoh, Ulysses and the SOlar and Heliospheric Observatory (SOHO). Instruments aboard these satellites have extended our gaze from the visible solar disk; down within the hidden solar interior and out in all directions through the Sun's tenuous atmosphere and solar wind. The relevant scientific themes are:

4. Inside the Sun.
5. The magnetic solar atmosphere.
6. The explosive Sun.
7. The Sun's winds.

The fourth theme discusses the internal structure of the Sun, and the way in which widespread throbbing motions of the visible solar disk have been used to measure the temperature, rotation and other gaseous flows within the Sun.

The fifth theme discusses the transparent million-degree gas, called the corona, which envelops the Sun and overlies the cooler, visible solar disk. This tenuous outer solar atmosphere is molded and constrained by magnetic fields, generated down inside the Sun and looping through sunspots into the corona. These magnetic loops interact and release magnetic energy when they make contact, providing an explanation for heating the million-degree corona.

The sixth theme describes sudden, brief, and intense outbursts, called solar flares, which release magnetic energy equivalent to billions of nuclear bombs on Earth. These violent explosions are easily detected at invisible X-ray and radio wavelengths, and are synchronized with the Sun's 11-year cycle of magnetic activity. Instruments aboard solar satellites routinely detect magnetic bubbles, called Coronal Mass Ejections and abbreviated CMEs, which expand as they propagate outward from the Sun to rapidly rival it in size, carrying up to ten billion tons of coronal material into interplanetary space. Both forms of explosive solar activity, the solar flares and the CMEs, can occur when magnetic fields come together and reconnect in the low solar corona, releasing stored magnetic energy.

The seventh theme provides an up-to-date account of the Sun's ceaseless winds that expand out in all directions, filling the solar system with an endless flow of electrons, protons and other ions, and magnetic fields. The origin and acceleration of the steady, high-speed wind and the capricious, gusty slow wind are discussed.

The interaction of the solar wind with the Earth's magnetosphere is included in the Space and Atmospheric Science Education Curriculum developed by OOSA [1]. Our eighth scientific theme further develops this topic, as discussed below.

8. The Sun's impact on Earth

The Earth's magnetic field shields us from the eternal solar gale, but gusts in the wind buffet our magnetic domain and sometimes penetrate within it. Forceful CMEs can create intense magnetic storms on Earth, trigger intense auroras in the skies, damage or destroy Earth-orbiting satellites, and induce destructive power surges in long-distance transmission lines on Earth. Energetic charged particles, hurled out during solar flares, endanger astronauts and can destroy satellites. Intense radiation from these flares increases the ionization of our atmosphere, disrupting long-distance radio communications and disturbing satellite orbits. Our eighth theme additionally examines the Sun's role in warming and cooling the Earth, including its contributions to global warming and to the creation of the ice ages.

9. Observing the Sun

We conclude the Sun part of the Space Science Education Curriculum with a description of the instruments and telescopes of solar astronomy. These include ground-based optical telescopes that study visible sunlight, gigantic arrays of radio telescopes that also observe the Sun from the ground, and satellites that have been specifically designed to study the Sun in X-rays, ultraviolet and visible light.

4. Education curriculum for the moons and planets

Only in the past half century have we been able to send spacecraft to the planets and their moons, changing many of them from moving points of light to fascinating real worlds that are stranger and more diverse than we could have imagined. Humans have visited the Moon, and robot spacecrafts have landed on Venus and Mars. We have sent vehicles to the very edge of the planetary system, capturing previously unseen details of the remote giant planets, dropping a probe into Jupiter's stormy atmosphere, and perceiving the distant satellites as unique objects whose complex and richly disparate surfaces rival those of the planets. Probes have also been sent to peer into the icy heart of two comets, and robotic eyes have scrutinized the battered and broken asteroids.

The Planets and Moons half of our Space Science Education Curriculum describes this fascinating voyage of discovery. It follows the organization of *The Cambridge Guide to the Solar System* [4], and the Moons and Planets Navigation Tab of the NASA's Cosmos website.

The curriculum begins by introducing the planets and their moons with a brief historical perspective. It is followed by a discussion of their common properties, including craters, volcanoes, water, atmospheres and magnetic fields. The three scientific themes are:

1. Evolving perspectives—a historical prologue.
2. The new, close-up view from space—impact craters, volcanoes and water.
3. The invisible buffer zone with space—atmospheres, magnetospheres and the solar wind.

Impact craters are found on just about every body in the Solar System from the Moon to the icy satellites of the distant planets, but in different amounts that depend on their surface ages and with varying properties. Numerous volcanoes have resurfaced Venus, currently active volcanoes have turned Jupiter's satellite Io inside out, and there are eruptions of ice on Neptune's largest moon, Triton.

Liquid water, which is an essential ingredient of life, covers seventy one percent of the Earth's surface. Catastrophic floods and deep rivers once carved deep channels on Mars, and spring-like flows have been detected in relatively recent times. Water ice is ubiquitous in the outer solar system, including the clouds of Jupiter, the rings of Saturn, and the surfaces of most large satellites. There is even evidence for subsurface seas beneath the water–ice crusts of Jupiter's moons Europa, Ganymede and Callisto.

Our-third theme provides a comparison of the planetary atmospheres and magnetospheres, and it parallels the one given in the Space and Atmospheric Science Education Curriculum developed by OOSA. The greenhouse effect of Venus' thick carbon dioxide atmosphere has turned the planet into a torrid world that is hot enough to melt lead and vaporize oceans. Mars now has an exceedingly thin, dry and cold atmosphere of carbon dioxide; the red planet breathes about one-third of its atmosphere in and out with the Martian seasons. Jupiter's powerful winds and violent storms have remained unchanged for centuries, and Neptune has an unexpectedly stormy atmosphere. Saturn's largest moon, Titan, has an Earth-like atmosphere, which is mainly composed of nitrogen and has a surface pressure comparable to that of the Earth's atmosphere.

Jupiter's magnetism is the strongest and largest of all the planets, as befits the giant, while the magnetic fields of Uranus and Neptune are highly tilted. Guided by magnetic fields, energetic electrons move down into the polar atmospheres of Earth, Jupiter and Saturn, producing colorful auroras there.

The Planets and Moons half of the Space Science Education Curriculum next discusses the rocky worlds found in the inner solar system—the Earth with its Moon, Mercury, Venus and Mars. The scientific themes include:

4. Third rock from the Sun—restless Earth.
5. The Moon: stepping stone to the planets.
6. Mercury: a dense battered world.
7. Venus: the veiled planet.
8. Mars: the red planet.

It begins with our dynamic home planet Earth. Continents slide over the globe, colliding and coalescing with each other, as ocean floors well up from inside the Earth and remain in eternal youth. A thin membrane of air protects life on this restless world, and that air is being dangerously modified by life itself. Synthetic chemicals have been destroying the thin layer of ozone that protects human beings from dangerous solar ultraviolet radiation, and wastes from industry and automobiles are warming the globe to dangerous levels. The politicized debate over global warming is also described in the fourth theme.

In the fifth theme we continue on to the still, silent and lifeless Moon, a stepping stone to the planets. Twelve humans went to the Moon more than three decades ago, and brought back nearly half a ton of rocks. The rocks contain no water, have never been exposed to it, and show no signs of life. They have been used to trace out the Moon's history and to explain its origin.

We discover in theme 6 that Mercury has an unchanging, cratered and cliff-torn surface like the Moon, but it resembles the Earth on the inside. Here we also mention tiny, unexplained motions of Mercury, which led Einstein to develop a new theory of gravity in which the Sun curves nearby space.

The next theme 7 discusses veiled Venus, the brightest planet in the sky. No human eye has ever gazed at its surface, which is forever hidden in a thick overcast of impenetrable clouds. They are filled with droplets of concentrated sulfuric acid. Radar beams from the orbiting Magellan spacecraft have penetrated the clouds and mapped out the surface of Venus in unprecedented detail, revealing rugged highlands, smoothed-out plains, volcanoes and sparse, pristine impact craters.

Our Planets and Moons curriculum continues in theme 8 to the red planet Mars, long thought to be a possible haven for life. Catastrophic flash floods and deep ancient rivers once carved channels on its surface, and liquid water might have lapped the shores of long-vanished lakes and seas. But its water is now frozen into the ground and ice caps, and it cannot rain on Mars now. If any liquid water were now released on the red planet's surface it would soon evaporate or freeze. Yet underground liquid water may have been seeping out of the walls of canyons and craters on Mars in recent times.

Five spacecrafts have landed on the surface of Mars, failing to detect any unambiguous evidence for life. Corrosive chemicals have destroyed all organic molecules in the Martian ground, which means that the surface now contains no cells, living, dormant or dead. The future search for life on Mars may include evidence of microbes that can survive in hostile environments, perhaps energized from the planet's hot interior.

The third section of the Planets and Moons part of the Space Science Education Curriculum presents the giant planets, worlds of liquid, ice and gas. The three scientific themes discuss the individual planets with their satellites and rings:

9. Jupiter: a giant primitive planet.
10. Saturn: lord of the rings.
11. Uranus and Neptune.

Theme 9 presents giant Jupiter, where everything we see is a cloud. The clouds are swept into parallel bands by the planet's rapid rotation and counter-flowing winds, with whirling storms that can exceed the Earth in size. The fierce winds run deep and are driven mainly from within by the planet's internal heat. Jupiter is almost entirely a vast global sea of liquid hydrogen, compressed into a fluid metal at great depths. And above it all, Jupiter has a faint, insubstantial ring system that is made of dust kicked-off small nearby moons by interplanetary meteorites.

The ninth theme additionally provides up-to-date accounts of the four large moons of Jupiter, known as the Galilean satellites. The close-up scrutiny from the Voyager and Galileo spacecraft has revealed active volcanoes on Io, smooth ice plains on Europa, grooved terrain on Ganymede, and the crater-pocked surface of Callisto. Changing tidal forces from nearby massive Jupiter squeeze Io's rocky interior in and out, making it molten inside and producing the most volcanically active body in the solar system. A vast current of 5 million amperes flows between the satellite Io and the poles of Jupiter and back again, producing auroral lights on both bodies. There are no mountains or valleys on the bright, smooth ice-covered surface of Europa but a subsurface ocean of liquid water may lie just beneath its icy crust. Ganymede has an intrinsic magnetic field, the only satellite known to now generate its own magnetism.

Our curriculum continues in theme 10 with Saturn. Its astonishing rings consist of billions of small, frozen particles of water ice, each in its own orbit around Saturn like a tiny moon. They have been arranged into rings within rings by the gravitational influences of small nearby satellites that generate waves, sweep out gaps and confine the particles in the rings.

Saturn's largest satellite, Titan, has a substantial atmosphere composed mainly of nitrogen molecules, also the principal ingredient of Earth's air. Clouds of methane, raining ethane and flammable seas of ethane, methane and propane could exist beneath the impenetrable haze. We should find out what lies beneath the smog when the Cassini spacecraft arrives at Saturn, in July 2004, and parachutes the Huygens probe through Titan's atmosphere four months later.

Uranus and Neptune are treated together in theme 11, because of their similar size, mass and composition. Internal heat drives Neptune's active atmosphere, which has fierce winds and short-lived storms as big as the Earth. Both planets are vast global oceans, consisting mainly of melted ice and no metallic hydrogen inside. The magnetic fields of both Uranus and Neptune are tilted from their rotation axes, and are probably generated by currents in their watery interiors. The ring systems of both planets are largely empty space, containing dark narrow rings with wide gaps.

Neptune's satellite Triton revolves about the planet in the opposite direction to its spin. The glazed satellite has a very tenuous, nitrogen-rich atmosphere, bright polar caps of nitrogen and methane ice, frozen lakes flooded by past volcanoes of ice, and towering geysers that may now be erupting on its surface

The Planets and Moons theme of the Space Science Education Curriculum concludes with a discussion of the smaller worlds, the comets and asteroids, as well as of collisions of these bodies with Jupiter, the Sun and Earth. They are viewed as pristine remnants dating back to the origin of our Solar System. The scientific themes for this section are:

12. Comets.
13. Asteroids and meteorites.
14. Colliding worlds.

As discussed in theme 12, a trillion comets are hibernating in the deep freeze of outer space, and they have been out there ever since the formation of the Solar System about 4.6 billion years ago. Only a very few comets light up and become visible, and then for just a few weeks or months when tossed near the Sun. The solar heat vaporizes the comet's surface and it grows large enough to be seen. Two spacecrafts have now passed close enough to image a comet nucleus, of Comet Halley and Comet Borrelly, showing that they are just gigantic, black chunks of water ice, other ices, dust and rock, about the size of New York City or Paris. When these comets come near the Sun, their icy nuclei release about a million tons of water and dust every day, from fissures in their dark crust.

Meteor showers, commonly known as shooting stars, are produced when sand-sized or pebble-sized pieces of a comet burn up in the Earth's atmosphere, never reaching the ground. We continue in theme 13 with the rocky asteroids. There are billions of them in the main asteroid belt, located between the orbits of Mars and Jupiter, but they are so small and widely spaced that a spacecraft may safely travel though the belt. An asteroid's gravity is too weak to hold onto an atmosphere or to pull most asteroids into a round shape, and we could mine some of the nearby ones for minerals or water. The NEAR-Shoemaker spacecraft has circled the near-Earth asteroid 433 Eros for a year, examining its dusty, boulder-strewn landscape in great detail. Meteorites are rocks from space that survive their descent to the ground, and most of them are chips off asteroids. Organic matter found in meteorites predates the origin of life on Earth by a billion years; but the meteoritic hydrocarbons are not biological.

The concluding theme 14 discusses colliding worlds, including pieces of a comet that collided with Jupiter a few years ago, comets that are on suicide missions to the Sun, and an asteroid that wiped out the dinosaurs when it hit the Earth 65 million years ago. The Earth is now immersed within a cosmic shooting gallery of potentially lethal, Earth-approaching asteroids and comets that could collide with our planet and end civilization as we know it. The lifetime risk of dying as the result of an asteroid or comet striking the Earth is about the same as for death from an airplane crash, but a lot more people will die during the cosmic impact.

5. Global perspectives

An additional supplement to a Space Science Education Curriculum would be a discussion of artificial satellites that look down on planet Earth. The remote sensing and geographic information system (GIS) education programs are, for example, being implemented in UN-affiliated regional centers [13].

Geosynchronous satellites, that orbit the Earth at the same rate that the planet spins, stay above the same place on Earth to relay and beam down signals used for cellular phones, global positioning systems and internet commerce and data transmission. They can guide automobiles to their destinations, enable aviation and marine navigation, and permit nearly instantaneous money exchange or investment choices. Other satellites move in lower orbits and whip around the planet, scanning air, land and sea for environmental change, and terrestrial weather forecasting. Some of these artificial satellites provide worldwide information that can be utilized by all nations for agriculture, land use, water resources, weather and climate.

In closing, we should remember that there are many other artificial satellites that look down upon the Earth for military reconnaissance purposes, as part of today's computer-based technology which provides unprecedented knowledge of the exact location of friendly and opposition forces during battle, and precisely where to direct precision-guided bombs or missiles, sent from above or beyond enemy fire.

All of us should remain committed to the use of outer space for solely peaceful and scientific purposes. Space Science should remain completely separate from the military use of space. We hope that the United Nations and every nation in the world will continue to use all legal and political means to prohibit the militarization of space.

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